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Improving the size selectivity of the inshore trawl fishery of Nha Trang city, Khanh Hoa province, Vietnam

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Improving the size selectivity of the inshore trawl fishery of Nha Trang city, Khanh Hoa province, Vietnam.

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Summary

Trawling is an important fishing method used by the inshore fishermen of Nha Trang city, Khanh Hoa province, Vietnam. The inshore trawl fishery in Nha Trang city is known to have very low selectivity, which may not be a responsible fishing practice. The trawl nets of the fishery retain large numbers of juvenile individuals, which has negative effects on the marine resources. The goal of this thesis is to provide initial suggestions to improve the selectivity of the inshore trawl fishery of Nha Trang city in order to reduce the catch of trash fish and juveniles of economically important species.

To fulfil this goal, I performed the following steps: (1) studied the current status of juvenile and trash[1] fish caught by the fishery in order to gather information on the composition and sizes of untargeted species[2]; (2) studied the selectivity of conventional codends with different diamond mesh sizes and with a square mesh panel; (3) aimed to determine the willingness of fishermen to use a bycatch reduction device (BRD) to reduce the catch of juvenile individuals.

The status of juvenile specimens caught by the fishery was determined by: (1) direct access to trash fish samples from the trawlers of the fishery; and (2) catch notes made by the wives of fishermen who were responsible for selling the catch at landing points. The selectivity of the codends tested was studied during sea trials on chartered trawlers from the fishery where the cover codend method was used. I also interviewed the captains of the trawlers to collect information about their willingness to test future versions of a BRD.

We found that trash fish accounted for reasonable part of the catch by trawlers from the fishery and played an important role in the incomes of fishermen, especially fishermen from small trawler fleets (i.e., trawlers with an engine power of less than 33 Hp). The trash fish comprised several economically important species (i.e., *Cephalopoda* spp., Portunidae spp., Penaeidae spp., *Trichiurus lepturus*, *Saurida tumbil*, and *Epinephelus* spp.). Most of the economically important species in the trash fish category measured less than 13 cm in total

[1] A definition of trash fish is provided in paper I in this thesis.

[2] Untargeted species are defined as juvenile specimens.

length (TL), except for *Trichiurus lepturus* where TL could reach 15 cm. This project also showed that the current mesh size of the diamond mesh at the codend had very poor selectivity performance. An increase in the mesh sizes used by the fishery to the legal mesh size would help to increase the selectivity for lizardfish, shrimp, squid, and threadfin bream. In addition, increasing the current codend mesh size to match the legal mesh size would help to reduce the catch of trash fish significantly. However, the legal mesh size is not sufficient to totally protect juveniles caught by the gears. With the current situation, the legal mesh size would be accepted to compromise between the protection of juveniles and the economic loss of fishermen. In the future, mesh sizes which is larger than current legal mesh sizes are suggested. The square mesh panel also helped to reduce the catch of trash fish and increased the selectivity for squid and lizardfish. Fishermen from the small trawler fleet refused to use the BRD to release the juvenile individuals. Fishermen from the larger trawler fleets may use the BRD provided there is no reduction in their catch of small squid. Information learnt from interviews with fishermen showed that the fish stocks exploited by the studied trawl fishery are declining sharply and it is necessary to deliver suitable measures to protect the fish stocks. Improving selectivity of the trawls used in the fishery is one of the measures.

List of papers

Paper I: Hai P. Nguyen, Roger B. Larsen, Hong H. Hoang (2011). "Trash Fish" in a Small Scale Fishery: a Case Study of Nha Trang Based Trawl Fishery in Vietnam. Asian Fisheries Science 24 (3):387-396

Paper II: Hai P. Nguyen, Roger B. Larsen (2013). Effect of codend mesh size increases on the size selectivity of commercial species in a small mesh bottom trawl fishery. Journal of Applied Ichthyology, 29 (4): 762 – 768.

Paper III: Hai P. Nguyen (2013). Size selectivity of alternative codends in a mixed bottom pair trawl fishery (Submitted).

Paper IV: Hai P. Nguyen (2013). Willingness of fishermen to use a bycatch reduction device (BRD) and their attitudes toward an indiscriminate fishery. (Submitted to a Journal of Ocean and Coastal Management. This paper will be re-submitted again after some revisions based on comments of reviewers at the first round of reviewing).

Research Purpose

The purpose of this project was to provide initial suggestions to improve the selectivity of trawl fisheriy based in Nha Trang city, Vietnam. To fulfil this aim, the following objectives were specified.

- To gather initial information on the current status of the capture of juvenile and trash fish by the inshore trawl fishery based in Nha Trang city (Paper I).
- To investigate the selectivity performance of different diamond codend mesh sizes in the otter board trawling fleet of the Nha Trang fishery (Paper II).
- To assess the selectivity performance of codends with different diamond mesh sizes or witha square mesh panel in the codend in the pair bottom trawling fleet of Nha Trang fishery (Paper III).
- To determine the views of fishermen about the future utilisation of bycatch reduction devices (BRD's) to exclude juvenile specimens (Paper IV).

Introduction

1. Overview

1.1. The marine capture fisheries of Vietnam

Vietnam is located in the central part of the Southeast Asian region. The country has a coastline of 3,260 km and an exclusive economic zone of approximately one million square km (Fig. 1). Marine capture fishery is an important economic sector in the country, which provides 850,000 fishing jobs for local coastal residents (MARD, 2012). The total estimated catch from marine fisheries in the country was about 2,225,000 tons in 2010 (MARD, 2012). In 2011, there were 126,460 registered fishing vessels with a total engine power of 6,500,000 horse power (Hp) (VIFEP, 2012). There are also small fishing vessels (i.e., mostly vessels with an engine power of less than 20 Hp or without engines) that have not been registered by the owners at the fishery management agencies. About 80% of all the fishing vessels have an engine power of less than 90 Hp, which are classified by Vietnamese fisheries management authorities as inshore fishing fleets (Fig. 2).

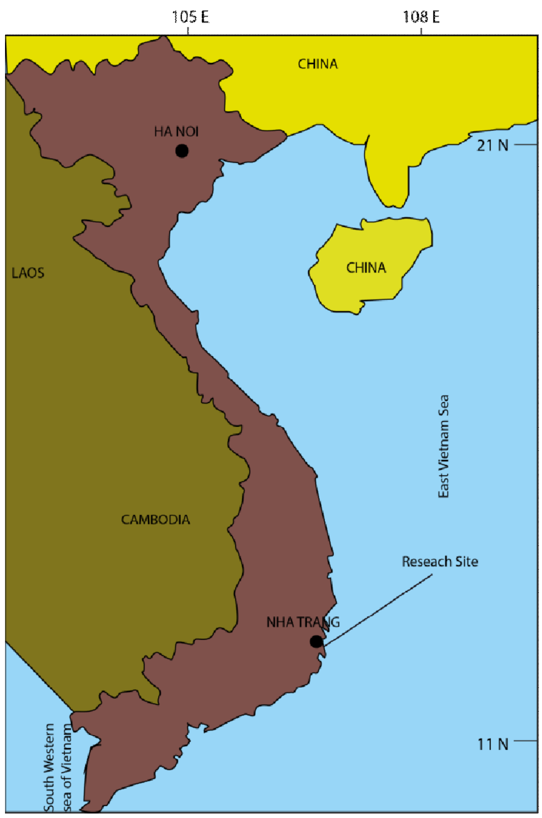

Figure 1: Map of Vietnam and the research sites.

Six main types of fishing methods are used by Vietnamese fishermen, i.e., trawling, gillnetting, tuna purse seining, line fishing, lift net & anchovy purse seine; and fixed gear (trap, stow net, etc.). Gillnetting is the most popular fishing method in the < 20 Hp fishing fleet, while trawling and gillnetting are the most popular fishing methods deployed by the 20– 90 Hp fleet. Trawling is also the most popular fishing method deployed by the > 90 Hp fishing fleet (Fig. 3).

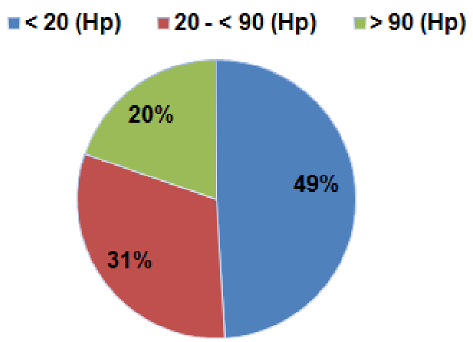

Figure 2: Fishing fleets of Vietnam (total fishing vessels: 126,460 vessels) (VIFEP, 2012).

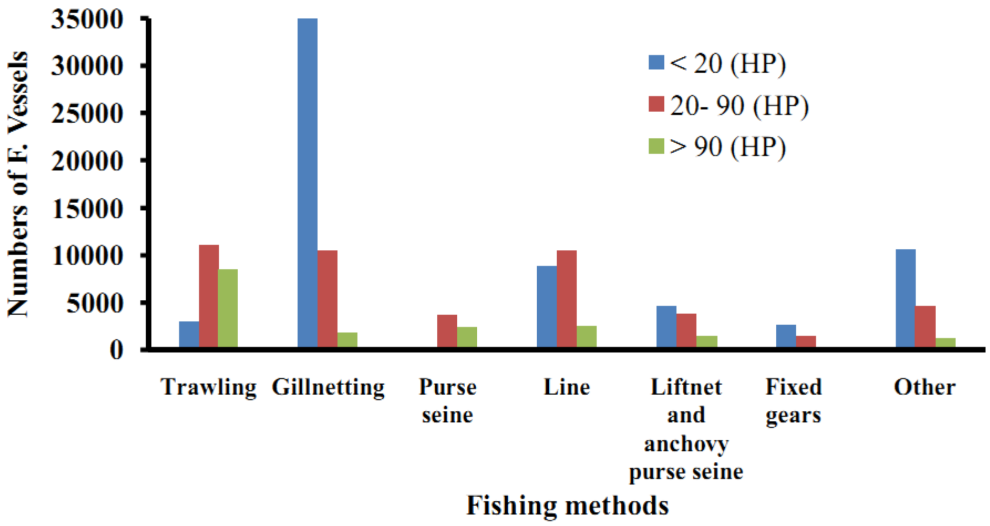

Figure 3: Numbers of fishing vessels by fishing method and engine power groups (MARD, 2012).

1.2. The trawl fishery based in Nha Trang city

Nha Trang city is located in central Vietnam (Fig. 1). Fishing is the main income source for the local coastal residents of the city. Trawling is the most popular fishing method used by local fishermen. The trawl fishery based in Nha Trang city has 403 trawlers (Decafirep, 2011), of which 134 vessels are bottom pair trawlers (67 pairs of pair bottom trawl) and the rest are otter trawlers (Fig. 4). There is no available data on the catch weight and catch value of the city's trawl fishery. The total landing from marine capture (i.e., including catches by all fishing methods) in the city during 2011 was about 72,895 tons (D_Fish, 2012, Hai et al., 2011).

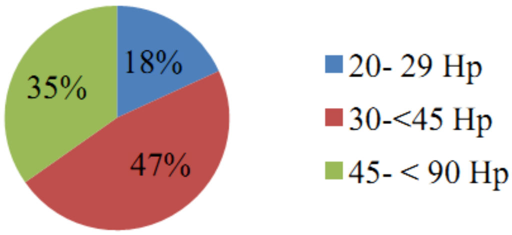

Figure 4. Registered trawlers in Nha Trang city (total: 403 vessels) (Decafirep, 2011).

The trawl net used by the fishery is a local modification of the traditional Asian trawl gear. The codend is made of machine-made net panels with 1.2 to 2.0 cm mesh sizes, while the other parts of the trawl net (i.e., the body, square, and wings) are woven manually by local female workers.

The catch is sorted manually into several commercial categories on board the vessel by the fishermen (see paper I, (Hai et al., 2011), for details of the sorted catch categories in the fishery). Fish, shrimp, crabs, and trash fish are placed in plastic boxes and covered by crushed ice. Squids are placed in plastic bags and all the bags are kept in plastic boxes covered by ice. All of the boxes are kept in the holds of the vessel. In the study fishery, there were no discards except for several poisonous types (e.g., sea snake, urchin, and jellyfish). A reasonable proportion of the catch categories were trash fish, which comprised damaged or small fish (mostly juveniles), or fish not accepted for human consumption. Catching a substantial amount of trash fish is not sustainable. In addition, it is a waste of natural resources if fish are captured and landed at the juvenile stage. Thus, trash fish and juvenile individuals should be released from the trawls to ensure a responsible fishing practice and the sustainable development of the trawl fishery.

- **Management**

The management of the fishery is based on several measures, including fishing zones restriction, minimum landing size, and minimum mesh size at the codend. All trawlers in the city need to apply for fishing permission from the Department of Capture Fisheries and Resources Protection of Khanh Hoa province (Decafirep, 2011). Minimum landing sizes are applied for several important species (MARD, 2006). The minimum mesh sizes at the codends of shrimp trawl and fish trawl nets are also regulated to 2.0 cm and 2.8 cm (nominal mesh), respectively (MARD, 2006). Recently, trawling was prohibited in the water bodies from the coastline to a defined lines along the coast of the country (Government, 2010) (see appendix I for the fishing zones regulated by Vietnamese Government) . In addition, the total weight of trash fish on each fishing trip should be less than 15% of the total catch (MARD, 2006). However, the monitoring and enforcement of the fisheries are not conducted properly due to the limited budgets of the fisheries management agencies. In this study, I observed that most of the aforementioned regulations are not followed by fishermen.

- **The trawlers.**

The trawlers of Nha Trang city are made of wood and equipped with inboard engines (Figs. 5 and 6). Each bottom pair trawler carries seven to ten fishermen. The larger boat of the pair, which carries the catch and net, has from five to seven fishermen while the smaller boat has two to three fishermen. Each otter trawler carries three to four fishermen. Typically, the owner of the boat is also the captain. The length of the vessels ranges from 12 to 15 m. The trawling fleet in the studied fishery was categorized into two main groups: (1) bottom pair trawlers with an engine capacity in each vessel that ranging from 45 to 89 Hp with some trawlers which have engine of larger than 90 Hp; and (2) otter trawlers with an engine capacity that ranged from 22 to 89 Hp, although most of them had an engine power of ≤45 Hp.

Figure 5. Otter board trawler.

Figure 6. The two vessels of a pair bottom trawl operation.

The fishing operation mechanization and navigation instrumentation on the trawlers are very limited. Warps, bridles and sweep lines are operated by a winch, while all of the other on board operations are manual. In general, one hydraulic trawl winch is installed on the vessel to pull in or let out the warp, sweeps and bridle (Fig. 7). The winch is operated by power extracted from the main engine. Only a GPS and a radio (Fig. 8) are installed in the vessel for navigation and communication at sea. The wheelhouse is in the aft section of the trawler and has an area of 5–8 m^2. This is also the place for the free-time activities of the crew members (e.g., eating, sleeping, and resting).

Figure 7. Winch installed in the middle of a trawler.

Figure 8. Navigation equipment in the wheelhouse (a GPS and a radio).

The boat is a typical Asian stern trawler where the codend is set out and retrieved from the side of the vessel. The setting out process (shooting) starts continuously from the codend, trawl body, wings, bridles, sweeps, otter boards (in otter trawling) and warps, and their operation is manual. The trawl net retrieval process (hauling) starts by pulling in the warps using the winch (rope-drum) up to the end of the sweeps. Next, the bridles, floatline, footropes and the net are pulled in manually at the stern of the vessel. When the codend reaches the vessel, it is moved by hand to the starboard mid-ship side of the trawler and then lifted on board the vessel manually, or with the help from a winch on the beam. The sorting and preserving of the catch is conducted on the open deck in the front part of the vessel. Appendix (II) illustrates some fishing operations on the trawlers.

1.3. Bottom trawl: descriptions and working principle

Trawling is one of the most important fishing methods in the world (Graham, 2010, Otto et al., 2005) and it is found in all coastal states (Winger et al., 2010). Trawl fisheries contributed 22% of the total landing of demersal species by the world's fisheries (Kelleher, 2005). Trawling belongs to a group of active/mobile fishing methods (e.g., trawling, purse seining) (Sistiaga, 2011, Suuronen and Francesc, 2007) where the fishermen manoeuvre the net to the moving path or to the positions of a fish school in order to catch the fish. The other group, passive fishing methods (e.g., gillnetting, trap fishing and line fishing), operate passively where the fish come to the nets and are caught (Suuronen and Francesc, 2007). Depending on the working position of the trawl net in the water column, trawling can be divided into: (1) bottom trawling when the net is towed close to (or at the) sea bed, or (2) pelagic trawling where the net operates in the free water column (with no part of the gear at the seabed). Bottom trawling can be divided further into: (i) pair bottom trawl (i.e., two boats towing one trawl net); (ii) otter bottom trawl (i.e., one boat towing one net); and (iii) multi-rig trawl (i.e., one boat towing two or more trawl nets at the same time). In Vietnam, otter bottom and pair bottom trawling are the main practices in the marine fisheries. In addition, small-scale beam trawling (i.e., the front part of the trawl is fixed to a metal frame and towed close to the seabed by one boat) is conducted mostly in the rivers of South Vietnam.

A trawl net has a body with a conical shape during operation. The aft section of the net, i.e., the codend, has a cylindrical shape and it is the section of the gear that retains the catch (Fig. 9). The other end, i.e., the front part of a trawl, comprises two wings and a trawl mouth, which opens vertically and horizontally to collect large volumes of water. The wings and mouth are rigged to the cables or ropes, which are known as the “leadline or footgear or footrope” and the “floatline/ or headline”, respectively (Fig. 9). In general, if fish are distributed homogeneously in the water, the larger the volume of water passes through a net, the larger volume of fish is caught during a trawl.

The vertical opening of a trawl is achieved mostly by floats attached to a floatline/ headline and weights attached to a leadline/ footrope (Fig. 9). In Vietnam, steel chains are attached to the footrope to increase the contact between the footrope and seabed in order to catch species living close to or on the seabed. The horizontal opening of a trawl is achieved using two otter boards (doors) during bottom otter trawling or by the distance between the two vessels in the pair bottom trawling operation (Fig. 9). Depending on the behaviour of the target species, a trawl can be designed and rigged to produce a more vertical opening (i.e., targeting round fish) or a more horizontal opening (i.e., targeting shrimp).

The two wing-ends of a trawl net are connected to the towing vessels (i.e., trawler(s)) by bridles, sweeps, otter- boards (i.e., there are no otter boards in pair bottom trawling) and warps (Fig. 9). In the studied trawl fishery, the typical lengths of bridles and sweep are 20 meters and 65 meters respectively in otter trawlers and 50 meters and 60 meters respectively for trawls deployed by bottom pair trawlers. The trawl net is towed by vessel(s) at a towing speed of 1.0 – 2.5 m/s depending on the nets, vessels and targeted species (Winger et al., 2010). The typical fishing depths for the studied trawl fishery would be in range from 80 m to 150 m.

In some shrimp trawl nets, the wing-ends are attached directly to the otter-boards, mainly in the tropical prawn trawling (Winger et al., 2010), because this type of shrimp trawl net does not require a high vertical opening. Small-scale trawlers or shrimp trawlers may tow a trawl net at towing speed as low as 1 m/s.

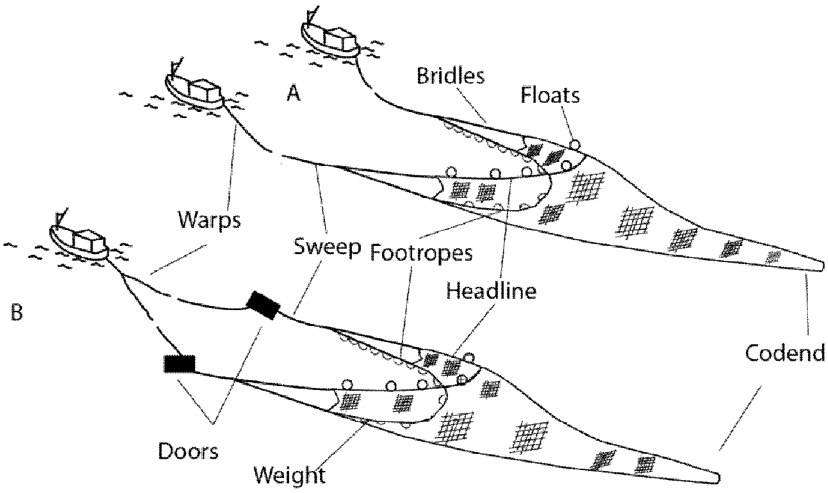

Figure 9. Principle components of two bottom trawl systems.

(A: Pair bottom trawling; B: Otter bottom trawling)

1.4. Codend selectivity during bottom trawling

The selectivity of a trawl refers to the ability to retain different sizes and species in the catch during a trawl based on the available aquatic population in the path where the trawl is towed (Wileman et al., 1996). A trawl may "select" to retain specific species from the population (species selection) or specific sizes of one species (size selection) (Wileman et al., 1996). This thesis is focused on the size selection of important target species and the exclusion rates of trash fish category.

Fish with a length, L, that enter a trawl net have a certain probability of being retained. The retention probability, r (L), of a fish with length L in a trawl net ranges from 0 (0% probability of retention) to 1 (100% probability of retention). The retention probability for a specific length of a fish is calculated by observing the number of the fish retained of that specific length and the number of fish of the same length that escape from the trawl. A plot created based on the length of fish (L) and the retention probability (r (L)) has a sigmoid curve (Wileman et al., 1996) (Fig. 10a). Several mathematical equations can be used to fit the observed data on trawl selectivity. A logistic function (Equation 1) may be used, provided the data are normal distributed. The curve fitted to the observed trawl selectivity data is known as a selectivity curve (Fig. 10a). Two important parameters of the selectivity performance of a trawl net are the L50% (length of fish at 50% probability of retention) (Equation 2) and SR (difference between L75% (length of fish at 75% probability retention) and L25% (length of fish at 25% probability retention); Equation 3; Fig. 10a). Assuming that the raw data are normally distributed, the S-shaped selection curve produced for mobile gear such as a trawl is equal to the cumulative distribution of the normal distribution curve. Thus, the selection curve is mirrored around the L50% value (and the value of L75% – L50% equal L50% – L25%). The relationship between the L50% and the mesh size used is known as the selection factor (SF) (see Equation 4).

$$r(L) = \frac{\exp(\alpha + \beta * L)}{1 + \exp(\alpha + \beta * L)} \text{ (Equation 1)}$$

In above equation, the parameters α and β are estimated by fitting a logistic equation (Equation 1) to the observed data using the least squares method (Wileman et al., 1996). Explanations of α and β are provided in appendix III (page 43). If the logistic model does not fit the observed data, other models can be used such as Richards, log-log or complimentary log-log models (i.e., see Wileman et al. (1996) for more details on other mathematic models used to fit the observed selectivity data).

The length at a 50% probability (L50) of retention can be calculated as follows:

$$L50 = -\frac{\alpha}{\beta} \text{ (Equation 2)}$$

The selection range (SR) (i.e., the difference between L25 and L75) is calculated as follows:

$$SR = L75 - L25 = \frac{2 * \ln 3}{\beta} \text{ (Equation 3)}$$

The selection factor (SF) is calculated as follow:

$$\text{SF} = \frac{\text{L50}}{\text{mesh size}} \text{ (Equation 4).}$$

The SF is a useful measure for predicting the effects on the L50% if the mesh size is changed, or for predicting the mesh size that need to be used to reach a specific L50. A detailed explanation on how to develop Equations 2, 3 and 4 from Equation 1 is also provided in appendix III.

The selectivity of a trawl depends on the species, trawl design (i.e., net material; (Tokaç et al., 2004, Deval et al., 2006), mesh size at the codend (Hendrickson, 2011, Queirolo et al., 2012), the mesh shape at the codend (Özbilgin et al., 2012, Campos et al., 2003), the codend circumference (Sala and Lucchetti, 2011, Broadhurst and Millar, 2009, Reeves et al., 1992, Graham et al., 2009) and the twine diameter (Graham et al., 2009)). In addition, other operating factors can affect the selectivity of a trawl such as the catch weight in the codend (Grimaldo et al., 2007, Campos et al., 2003, Jørgensen et al., 2006), the sea state (O ’ Neill et al., 2003), the towing speed and the trawling depth.

Selectivity occurs in all the parts of a trawl but the most important positions are the codend and the extension of the trawl net (Beverton, 1963). Thus, most selectivity studies have concentrated on these parts. In addition, the mesh size, twine diameter and codend circumference are the most important factors that affect the selectivity performance of a codend. In general, an increase in the codend circumference or twine diameter will reduce the L50 of a diamond mesh codend (Graham, 2010).

If the L50 is altered while the SR remains the same, the selectivity curve will move horizontally to the left or right. If the L50 of a trawl for a species is below the existing minimum landing size (MLS), most of the individuals of that species larger than the MLS will be retained. However, a large number of the fish below the MLS will also be retained (Fig. 10b). The undersized fish brought onboard the vessels are discarded by fisheries in several developed countries or landed and sold as low value fish in several developing countries. To address the problem of a low L50 (i.e., L50 < MLS) (Fig. 10b), the trawl should be modified to improve its selectivity to achieve a larger L50. By contrast, if the selection curve moves horizontally to the right in order to achieve a larger L50 (i.e., >MLS), a larger proportion of fish below the MLS would will excluded from the trawl. Depending on the SR, some of the fish above the MLS will also be excluded, which causes losses for fishermen and creates an incentive for them to reduce the selectivity of their trawl nets (Fig. 10c). If L50 remains the same but the SR of a trawl increases (Fig. 10d), a larger proportion of undersized fish will be retained but more fish above the MLS will also be excluded from the trawl. This has detrimental effects on the economic efficiency (i.e., losses of marketable sized fish) and environmental conservation (i.e., retention of undersized fish). Thus, in addition to achieving a sustainable L50, fisheries scientists and fishermen always aim to reduce the SR of a trawl to the minimal level.

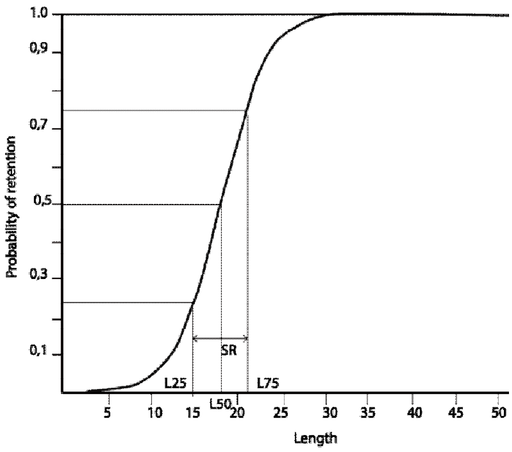

Figure 10a. Selection curve of a trawl

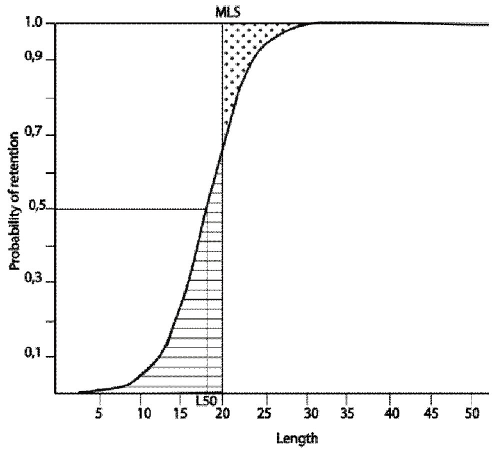

Figure 10b. Selectivity with L50 < MLS.

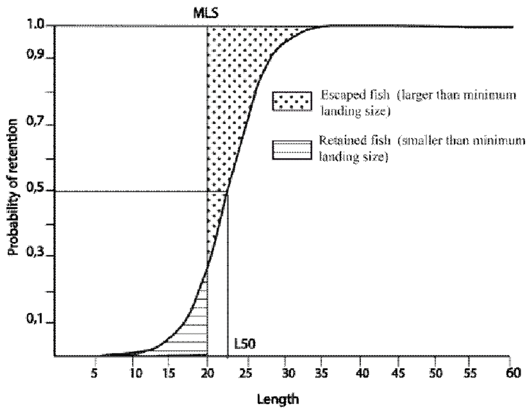

Figure 10c. Selectivity with L50 > MLS.

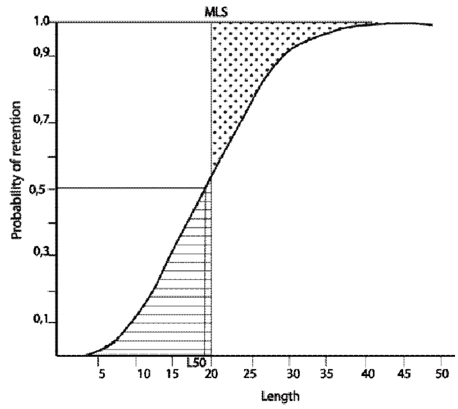

Figure 10d. Selectivity with large SR.

During a selectivity study, several experimental trawling hauls should be analysed. Even if the same net or selectivity devices (e.g., grid or square mesh panel) are used, the selectivity parameters (i.e., SR and L50) of the net can fluctuate among hauls. This is because there are variations between the hauls. The between-haul variation depends on the trawl net and/or selectivity devices, as well as other factors such as diurnal changes in the population being fished (i.e. its species and size composition), catch weight, seasons and trawling depth. Selectivity studies may have several outcomes where the mean selectivity parameters are the targets (i.e., the mean of several individual hauls). Selectivity parameters are used to compare the selectivity performances of two codends. In the case if the selectivity parameters of the compared codends are similar, variations of the parameters will be considered.

If a grid or a square mesh panel is placed in the codend, fish may try to escape through the grid/panel or through the codend meshes. Firstly, fish that reach the grid or a square mesh panel may try to escape through these devices. Those fish that cannot escape from the sorting device (i.e. grid or square mesh panel) will have another chance to escape through the codend meshes. There is evidence that not all of the fish that reach the vicinity of the grid will attempt to escape (Sistiaga et al., 2010, Zuur et al., 2001). The process whereby fish escape through the combined grid (or square mesh panel) and codend system is described as a dual selection process (Sistiaga, 2011). According to Sistiaga et al. (2010), a model that accounts for the fraction of fish that attempt to escape through the square mesh panel and from the grid and from the codend mesh is better than the original logistical equation (Equation 1, page 18). These models were developed and introduced to deal with the study of dual selection (see (Sistiaga et al., 2010, Zuur et al., 2001)for detailed explanations of the models).

1.5. The trawl selectivity experiment

To assess the selectivity performance of a codend (tested codend) or a selectivity device, scientists need to know the numbers of fish in each size class that enter the codend or that reach the affected areas of the selectivity device, as well as the number of fish that escape through the codend or selectivity devices. Field experiments are conducted to collect *in situ* data and six methods are commonly used to collect the selectivity data from a trawl net. The covered codend method was applied in the experiments described in this thesis and it is explained in this section. The other methods normally used in selectivity studies are presented in appendix IV (pages 47-48).

- **The covered codend method**

A small-meshed bag, known as the “cover”, surrounds the test codend in order to retain all of the specimens that escape through the codend meshes. According to Wileman et al. (1996), the fully extended width of a cover should be at least 1.5 times larger than that of the test codend and the length of the cover is advised to be two times longer than the extended length of the test codend. The construction of the cover should ensure that the water flow in and around the test codend is affected as little as possible. The cover codend is usually attached to hoops or kites to avoid contacts (masking) with the tested codend. There are three main advantages of this type of selectivity study: (1) each successive haul would produce one selection curve; (2) the estimation of fish entering the codend is accurate and (3) the same method would be used for different trawls which allows selectivity comparison among the trawls (Wileman et al., 1996) . However, this method has the disadvantage of a possible bias because the cover can affect fish behaviour due to the changes in the water flow in and around the tested codend (a sketch of the covered codend method is provided in Nguyen and Larsen (2013)).

1.6. The importance of trawl selectivity studies

Studies of the selectivity of trawl net are very important for reducing the negative effects of trawling on natural resources. It is generally believed that a good selective fishing gear is more eco-friendly because it reduces the catch of non-target species and/or fish sizes. Based on the selectivity performance determined by trawl selectivity studies, fisheries scientists and managers can decide the minimum mesh sizes as well as non-target species excluding devices for the studied fishery. In addition, selectivity studies can help to manage the catch (i.e., fishing mortality) of a fishery. Fishing mortality relates the fishing effort to the catch-ability. The catch-ability is partly affected by the selectivity of fishing gear. Thus, managing the selectivity of fishing gear will help to modify the catch-ability of that gear, as well as helping to manage the fishing mortality of a fishery (Wileman et al., 1996). Fisheries management is governed by the total allowable catch, which is estimated by fish stock assessment. However, in a fish stock assessment method that relies on the length frequency data of the fish population, the selectivity of the trawl is also important for correcting the retrieved fish length data by adjusting the catch-ability of the net (Jenning et al., 2006). In some fisheries experiments that use fishing gear to collect fish, the selectivity (selection characteristics) of the gear is needed to know the potential bias caused by that gear, i.e., a certain proportion of fish will escape (Jenning et al., 2006). Kvamme and Frøysa (2004) used a model to predict the changes in catch and stock sizes with different selectivity parameters of the trawl gear and they found that increasing the L50 by 5 to 8 cm from 47 cm in the Northeast Arctic cod fishery increased the catches and stocks size of the cod (*Gadus morhua*). In addition, the catch of 3–4-year-old fish was reduced, while there was increases of catch of + 6 years olds cod within a few years (Kvamme and Frøysa, 2004) . The study of Kvamme and Frøysa (2004) was an example of the prediction on the catch and stock size based on different suggested selectivity parameters .

Information on the selectivity of fishing gear is very important for estimating the total fishing mortality. According to ICES (2005), the total fishing mortality is the sum of the different sub-components of mortalities and can be expressed as follows:

$$F = Fc + Fb + Fd + Fe + Fo + Fg + Fa + Fh$$

where F is total fishing mortality; Fc is land catch ; Fb is illegal, misreported and unreported landings; Fd is discard mortality; Fe is escape mortality; Fo is drop out mortality; Fa is avoidance mortality; Fg is ghost fishing mortality and Fh is habitat degradation mortality (see ICES (2005) for detailed explanations of each type of mortality). The discard and escape mortality were not counted in the original fish stock assessment models. When these two types of mortality are high, the fish stock assessment will have a substantial bias. Estimation of the discard and escape mortality from the gear is necessary to estimate the total fishing mortality. There are different methods for estimating these two types of mortality and information on the selectivity of the fishing gear is used to estimate the discard and escape mortality (Harley et al., 2000). Breen and Cook (2002) also proposed a model for estimating the total fishing mortality that used the selectivity of the gear, the discard rate, and the discard and escape mortality of the gear.

2. Responsible fisheries and the need to improve the selectivity of trawl nets in Vietnam

In 1995, as a reaction to concerns over the unsustainability of fisheries activities, the Food and Agriculture Organisation of the United Nations (FAO) developed a Code of Conduct for Responsible Fisheries (the Code) (FAO, 2011). The Code is a guideline for coastal countries to ensure that their fisheries activities are sustainable. The concept of “Responsible fisheries”, mentioned in the Code, encompasses “*the sustainable utilization of fisheries resources in* *harmony with the environment; the use of capture and aquaculture practices which are not harmful to ecosystems, resources or their quality; the incorporation of added value to such products through transformation processes meeting the required sanitary standards; the conduct of commercial practices so as to provide consumers access to good quality products*" (FAO, 2011). The Code is voluntary for all coastal countries but it highlights international concerns about the issue of the responsible use of living marine resources by countries.

In 2009, the Southeast Asian (SEA) Fisheries Development Center (SEAFDEC) prepared *Regional Guidelines for Responsible Fishing Operations In Southeast Asia* (the Guidelines), which are detail guidelines for countries in the region for following the responsible fishing practices mentioned in article 8 of the FAO Code (SEAFDEC, 1999). The Code and the Guidelines encourage coastal countries in the SEA region to employ selective fishing gear and to minimise bycatch and discards in their fisheries (SEAFDEC, 1999, FAO, 2011). In addition, the Guidelines also urge regional countries to propose policies that reduce the catches of juveniles of aquatic species (SEAFDEC, 1999).

Inshore areas of Vietnam are over-exploited (WorldBank, 2005) and fisheries activities in these areas should be conducted with respect for the conservation and sustainable use of resources. The trawl fishery based in Nha Trang is not compliant with the Code and the Guidelines for responsible fishing. Their trawl nets have poor size selectivity and they catch a high proportion of juvenile fish. This has negative effects on marine resources and poses threats to the social and food security of the City. Thus, it is necessary to improve the selectivity of the trawl nets to improve the sustainability of the trawl fishery. Improving the selectivity of trawl fishery will also help to avoid a decline in fish stocks thereby leading to the sustainability of the livelihoods of fishermen in Vietnam who have limited access to other sources of incomes.

3. Modifications of bottom trawls to reduce the catch of juvenile fish

Trawl net modifications to reduce the bycatch can be classified into two categories: (1) modifications based on differences in the behaviours of targeted and untargeted species; and (2) modifications based on differences in the sizes of targeted and untargeted species (Broadhurst, 2000, Eayrs, 2007). The separation of the catch based on the size of specimens is more suitable for the inshore trawl fishery based in NhaTrang city because it aims to reduce the catch of juvenile specimens while maintaining the retention of larger size adults. This section reviews methods for increasing the mesh size at the diamond mesh codend and for adding a square mesh panel to the diamond mesh codend in order to reduce the catch of juvenile specimens in the trawl net. These two methods were tested in this project. Some other methods that may be applied to reduce the catch of juvenile individuals are reviewed in appendix V of this thesis. Broadhurst (2000) and Eayrs (2007) reviewed and introduced more details of modifications for reducing the bycatch based on size and species differences.

3.1. The codend mesh size

The first option that affects the size selectivity of a trawl is modification of the mesh size in the codend (Eayrs, 2007). If the size of the diamond mesh is increased, the mesh opening will also increase, which gives a higher probability of a round-shaped fish escaping though the mesh opening in the codend. Thus, most coastal countries have regulations on the minimum codend mesh size to protect undersized specimens. However, the diamond mesh tends to close due to drag forces along the towing direction when the net is towed and when the catch accumulates in the codend (Graham et al., 2009), which restricts fish to escape through the opening in diamond meshes.

In addition to the low selectivity of diamond mesh, the survival of escaped fish from the diamond mesh codend is probably low. Underwater observations show that juvenile cod escaped mostly through the diamond mesh codend in the retrieval stage when the net is near the water surface (Grimaldo et al., 2008) and that late escape reduce the survival of escaped fish (Suuronen, 2005). Fish have a greater chance of survival if they can escape immediately when they reach the codend or grids while the gear is still in the catch process (i.e. at the fishing depth).

3.2. Square mesh codends/panels

In contrast to diamond meshes, which gradually close during operation, underwater observations show that square meshes remain open during towing because the tension/drag forces follow the lengthwise bars. Thus, square meshes provide more opportunities for fish to escape through open meshes. There have been attempts to use square mesh codends or adding square mesh panels to diamond mesh codends in order to allow undersized fish to escape through the codend (Broadhurst and Kennelly, 1997, Broadhurst et al., 2004, Broadhurst et al., 1999, Grimaldo et al., 2007). In comparison with a diamond mesh codend with the same mesh size, a square mesh codend produced up to 50%- higher in L50 and a smaller SR for several species (Broadhurst et al., 2004, Halliday and Cooper, 2000). Grimaldo et al. (2007) showed that a square mesh window (130 mm mesh size) released a larger amount of undersized fish and the L50s of cod and haddock (*Melanogrammus aeglefinus*) were above the MLS. According to Broadhurst et al. (1999), a 52-mm square mesh codend in a prawn trawl fishery in Australia reduced unwanted commercial fish by up to 96.9% while it still retained the catch of prawns. A square mesh window helped to release 71% (by weight) of the bycatch in an estuarine squid-trawl fishery in New South Wales, Australia (Scandol et al., 2006). A full square mesh codend is mandatory in some Northwest Atlantic and EC Mediterranean demersal trawl fisheries (Graham, 2010) in order to protect juvenile fish. A square mesh window is mandatory in North Sea Whitefish fisheries (Bullough, 2007). A codend with an upper panel made mostly from square mesh (BACOMA codend) is mandatory in Baltic cod fisheries (Graham, 2010).

4. Research approach

In order to improve the selectivity of a trawl fishery, it is important to understand the status of target and unwanted species and their sizes. Information on the species is important for selecting appropriate solutions/selectivity techniques to improve the selectivity of the fishery. In addition, the weights and values of the untargeted catch that needs to be excluded by the solutions will help to quantify the possible economic impacts of the implementation of selectivity solutions.

In the Nha Trang trawl fishery, the untargeted species/individuals could not clearly be defined because all of the catch was retained to sell at the fishing ports. To study responsible fishery practises, the untargeted catch in this project was defined as trash fish and the juveniles of economically important fish species (see paper I for a description of trash fish). The status (i.e., species composition and length frequency of selected species) of juvenile and trash fish caught by the trawl fishery based in Nha Trang was examined by the direct analysis of trash fish samples taken from trawlers after each fishing trip. In addition, information on the trash fish proportion (weight and value) of the trawl fishery was collected via co-operation with the wives of fishermen who were responsible for selling the catches in the fishing port. The wives of the fishermen were asked to note information on the sold catch (weight and money). Initial information on the status of juvenile and trash fish caught by the fishery are provided in paper I.

Sizes of diamond meshes at a trawl codend is always the first factor that needs to be considered to improve the selectivity of a trawl fishery (Dante et al., 2012, Eayrs, 2007). Comparisons of the selectivity performance with conventional size, legal size and larger size diamond meshes at the codend are important for determining the effects of different diamond mesh sizes on selectivity in the study trawl fishery. The selectivity performances of different codend mesh sizes were assessed during field experiments on chartered trawlers and using the covered codend method. The trawl nets used in the experiments were the same as the existing trawl nets used by the chartered trawlers, except for the tested codends. Paper II presents the outcomes of the field experiments to determine the selectivity of different diamond mesh sizes. In addition, the selectivity of a diamond mesh codend with a square mesh panel was also analyzed in a pair bottom trawler to obtain initial information on the selectivity of this device (paper III).

To ensure the success of new management solutions used by a fishery, it is important to understand the views of fishermen on the solutions and their willingness to adopt modifications of their gear. In this project, the views of fishermen on the exclusion of trash and juvenile fish from their trawl were collected. Both closed- ended and open-ended questions were used to ask the captains of the trawlers in the fishery about their views on the future use of techniques/ devices to reduce the catch of juveniles from their trawl nets (paper IV).

5. Sea trials and research limitations

5.1 Chartered fishing vessels

All of the field trials presented in this thesis were conducted on board chartered trawlers in the studied fisheries. The experiments described in paper II were conducted on board a bottom otter trawler (F/ V KH 91711) while the trials in paper III were performed on board a pair bottom trawler (F/ V. KH 5687 & F/V. KH 5763). F/ V. KH 91711 was 12.5 m long and equipped with a 76 Hp engine. F/ V. KH 5687 was 13 m long and equipped with a 56 Hp engine while KH 5763 was 13.5 m long and equipped with a 89 Hp engine. The chartered trawlers were typical of the fisheries with respect to their hull sizes, engine power and trawl net designs.

It is time-consuming to sort the catch and to measure the length of specimens in a tropical fishery. The catch in the field trials comprised more than 20 species and the specimens were very small (Fig. 12 a, b, c, d). It would have been impossible to measure all of the species caught by the experimental nets in the selectivity study. Thus, the most economically important species were selected for the study and sub-samples were collected for length measurements (papers II and III). Chartering trawler is always expensive and the catches obtained after measuring should be preserved for direct sale at the landing point in order to reduce the costs of the experiments. Thus, we could not bring the catch to the research lab on land for detailed measurements.

The selectivity studies presented in this thesis were conducted in the Nha Trang trawl fishery where crew members were not familiar with this type of research. In addition to the four to seven fishermen onboard, at least five scientists also worked on the vessels during the sea trials sorting and measuring the fish. Asian trawlers are very small and the working conditions were difficult. There was not enough space for the vessel and scientific crews to rest after working. Thus, we could not remain at sea at night to wait for the next fishing day. This increased the experimental costs when moving from the fishing port to the fishing grounds and returning to the home port (i.e., 4 h lost per day).

5.2. The experimental design

The covered codend method was used in the field trials presented in this thesis (see more details on the construction of the covers in papers II and III). The cover was attached to two hoops to ensure clearance between the tested codends and the cover (Fig. 12 e, f). The covered codend method was chosen because this method reduces the experimental costs compared with the parallel haul or alternate haul methods. Other methods for gathering selectivity data were also evaluated, but were rejected due to the complexity of their experimental designs and cost. The twin trawl method was not selected because it was very complicated and costly to set up a new net system. In addition, the captain and crews were not familiar to the operation of twin trawls. Limitations on electronics and instruments (i.e., no underwater sensor system was available for monitoring the net) made it difficult to setup a new trawl rig system. The trouser trawl method was not selected because of worries about the possible bias associated with the water flow inside the net when the normal codend is divided into two separate and smaller codends.

5.3. Limitations

The field trials were conducted onboard the most typical sizes of trawlers in the studied fishery. Experiments on other trawler sizes in the fishery would provide more details on the selectivity performance of the devices tested for the whole fishery. In addition, sub-samples were collected in the field experiments to obtain length data, which may have caused some bias in the selectivity study. Although the effects of the sub-samples were included in the calculations of the selectivity parameters, a small bias may still have existed. The mesh size of the cover was small (5 mm bar length), and this substantially affected the water flows in and around the test codend, which also affected the fish behaviour. Thus, the front part of the cover was left open with the arm (see drawing in Fig.1 in Nguyen and Larsen (2013)). The opening in the front part of the cover allowed water to move freely around the tested codend. However, this design may have created some bias due to the escape of fish from the cover when hauling the net.

a

b

c

d e f

Figure 11. (a): Catch of a haul; (b): Sorting catch retained in codend; (c): Sorting catch retained in cover; (d): Length measurement of a juvenile fish; (e): Cover with hoops; (f): Detaching cover from tested codend.

6. Summary of outcomes

6.1. Status of the trash fish caught by the trawl fishery based in Nha Trang city (paper I)

Trash fish accounted for 23% and 22%, respectively, of the total catch by the bottom pair trawling and the otter trawling fleets. However, only 8% and 11%, respectively, of the revenues of the bottom pair trawling and the otter trawling fleets were from selling trash fish. Cardinal fish (*Apogon* spp.), greater lizardfish (*Saurida tumbil*), sin croaker (*Johnius dussumieri*) and pony fish (*Leiognathus* sp.) were among the most abundant species of trash fish. There were also large numbers of shrimp and squid, species with a high economic value, in the trash fish category (see paper I). The catches of the pair trawling fleet were dominated by trash fish, largehead hairtail (*Trichiurus lepturus)*, *Loligo* sp. and *Decapterus* sp., whereas the catches by otter trawling were dominated by trash fish, largehead hairtail and Penaeidae sp. Most of the individuals in the trash fish category were smaller than 13.0 cm, except for largehead hairtail with a total length that could reach 15 cm.

The species composition included shrimp, squid, fish (both round- and flat-shaped fish) and crab in the trash fish category. For the catch value, shrimp and squid were the most important parts for otter trawlers while squid and largehead hairtail were the most important catches for pair bottom trawlers. Shrimp and squid were target species for selectivity studies of otter trawl nets while squid was one of the target species for pair bottom trawl nets in the study. Largehead hairtail accounted for about 5% of the total weight of trash fish, but this was due to the existence of several large, but damaged individuals. There was a low number of small largehead hairtail. Thus, largehead hairtail was not an urgent priority for the selectivity study in this project. Threadfin bream (*Nemipterus* sp.) did not have an important role in the catch of the pair trawl fishery. However, there were worries from the fishermen about a sharp reduction in this species in the fishing grounds (i.e., personal communication with Mr Nguyen Van Beu and Nguyen Van Hieu, the captains of the chartered fishing trawlers). Thus, improvements in the selectivity of trawl nets used for threadfin bream are needed.

6.2. Legal mesh size in the codend: Does it work to protect juvenile individuals in the bottom otter trawls? (Paper II)

Table 1: Summary of selectivity parameters

Codend 1: 11.6 mm, DM*					Codend 2: 25 mm, DM				Codend 3: 28.7 mm, DM		
Species	L50	SR	SF		L50	SR	SF		L50	SR	SF
Shrimp	8.33	1.53	0.71		11.86	2.55	0.47		13.92	6.26	0.48
Greater Lizard fish	NA	5.51	3.9 - 4.9**		10.94	2.44	4.4		14.59	0.84	5.1
Squid	1.31	0.75	1.1		3.61	0.93	1.4		4.19	1.38	1.5

**. DM: diamond mesh; Shrimp was measured with carapace length in mm; Fish was measured with total length in cm and Squid was measured with mantal length in cm.*

*NA: Insufficient data to produce a L50; ** Inference drawing from SRs of 25 and 28.7 mm codends.*

The effects of increasing the codend mesh size from 11.6 to 25 and 28.7 mm (inside stretched mesh or lumen size) on the selectivity of greater lizardfish, squid and penaeid shrimp were assessed. Increasing the mesh size did help to increase the L50s for the examined species and it also helped to reduce the quantity of trash fish retained by the codend. The diamond mesh codends with mesh sizes of 11.6, 25 and 28.7 mm selected shrimp at L50s of 8.33, 11.86 and 13.92 mm (carapace length), respectively. In addition, SRs of shrimp for the above codends were 1.40, 2.55 and 6.26 mm, respectively. The L50 values for greater lizardfish increased from

10.94 cm in the 25 mm codend to 14.59 cm in the 28.7 mm codend. Insufficient data precluded an estimate of L50 for this species with the 11.6 mm codend. However, the results for the 25 and 28.7 mm codends indicated that the SF for this species was 3.9–4.9 cm, which suggests a L50 for the 11.6 mm codend of 5.8–7.4 cm. The L50 values for squid were 1.31, 3.61 and 4.19 mm (mantle length), respectively, for the 11.6 to 25 and 28.7 mm codends. The mean proportions of escaped trash fish were 0.06, 0.68 and 0.85 for the three codends, respectively. The study also showed that the use of a specific lumen size in the diamond mesh was more precise than the overall mesh size (i.e., knot to knot centre), which has been used in the current regulation on the minimum mesh size. Initially, a minimum mesh size of 25 mm (lumen size) is a good compromise between the management objective of responsible fishing and fishermen's acceptance of the loss of trash and juvenile fish. In the future, larger mesh size is required to fully protect the juveniles.

6.3. Codend mesh size and square mesh panel to improve the selectivity of pair bottom trawls (Paper III)

	*Codend 1				**Codend 2				***Codend 3		
Species	L50	SR	SF		L50	SR	SF		L50	SR	SF
Squid	2.7	1.8	1.25		2.9	1.5	1.16		3.7	2.4	-
Greater Lizard fish	8.1	1.6	3.76		11.9	7.9	4.76		12.2	1.7	-
Threadfin Bream	5.6	1.2	2.6		12.2	7.9	4.88		7.9	3.4	-

**Codend 1: 21.5 mm (lumen size); **Codend 2: 25 mm (Lumen size); ***Codend 3: 25 mm + square mesh window (25 mm); Fish was measured with total length in cm and Squid was measured with mantal length in cm. SFs for the studied species of codend 3 has not been estimated since the selectivity system included both the mesh opening and square mesh window.*

In this study, we analysed the size selectivity for lizardfish, threadfin bream and squid using three codends: (1) 25 mm diamond mesh (nominal mesh) throughout (21.5 mm lumen size); (2) 28 mm diamond mesh (25 mm lumen size); and (3) 28 mm diamond mesh (25 mm lumen size) with an added 28 mm (25 mm lumen size) square mesh panel on top. A change in the mesh size of the diamond-shaped meshes at the codend from 21.5 mm to 25 mm (lumen mesh) helped to increase the L50s of lizardfish, squid and threadfin bream by 47%, 7% and 41 % respectively. The diamond mesh codend with a square mesh panel used in this study helped to increase the L50 of lizardfish and squid but did not significantly affect the L50 of threadfin bream. The reduction of trash fish retention by codends was achieved by increasing the mesh size of the diamond mesh at the codend from 21.5 mm to 25 mm fish. In addition, the retention of trash fish was also decreased by installing the square mesh panel into the top panel of the diamond mesh codend. The trash fish retention by the test codends declined continuously with 21.5 mm, 25 mm and 25 mm plus square mesh panel codends by 13% (Wt.%, SE = 1 %), 20% (Wt.%, SE = 1.5%) and 26% (Wt.%, SE= 2%) respectively.

6.4. The views of fishermen on the application of bycatch reduction devices (BRD) to release juveniles and trash fish (Paper IV)

For the small sized trawler group in the fishery (i.e., trawlers with an engine power of <33 Hp), fishermen were not ready to use a BRD because of their economic dependency on selling trash fish. Fifty percent of the respondents in the medium-sized trawler group (i.e., otter trawlers with an engine power of 33–89 Hp) and 60% of interviewees in the large-sized trawler group said they would use the BRD if it did not affect their catch of small squid and octopus. According to these fishermen, the average catch had declined by about 5.5% each year for the last 10 years. All respondents worried about alternative incomes in the periods when they were not fishing due to possible time closure regulations. A lack of awareness of fisheries regulations was another reason for non-compliance by fishermen. Currently, the BRD for reducing juvenile and trash fish would only apply to medium and large size trawl fleets where the expectation of fishermen was a “zero” loss of small squid. It is not feasible to meet this expectation, but the effect on the loss of small squid should be considered in future studies.

7. Conclusions and suggestions for future work

The papers in this thesis contain initial information, which is necessary to improve the selectivity of the trawl fishery based in Nha Trang city, Vietnam. Paper I provides information on the status of the trash and juvenile fish caught by the trawl fishery. Papers II and III investigated the use of different mesh sizes in the diamond mesh codends to improve selectivity. The outcomes showed that the current mesh size used by fishermen has very poor selectivity. In addition, the current legal mesh size is not adequate to reduce the catch of juvenile individuals. However, attention should be paid to seek a compromise between the loss of income for fishermen by using larger mesh sizes and the objective of sustainable fisheries management. The views of fishermen on the future use of BRDs to reduce the bycatch and juveniles were investigated. Many fishermen from the larger vessels had positive attitudes to the techniques and regulations.

The Nha Trang trawl fishery has existed for over 40 years and has increased gradually. Fishermen have reported dramatic changes in the ecosystem and they have worries and uncertainties about the future. Long-term declines in the catch rates are the first evidence of overexploited fish stocks. Several input controls could be applied to reduce the fishing pressure in the area. In many parts of the world, quota restrictions, restrictions on the number of fishing days, and the number of fishing licences and vessels are enforced. Complicated political decisions of this kind are still premature in this society because the Nha Trang fisheries sector lacks basic information on stock levels, biomass and recruitment. As a first attempt to move the Nha Trang trawl fisheries towards more responsible practices, I would suggest greater efforts in the improvement of selective fisheries. This may be unpopular in certain areas of the fisheries but it is one of the easiest and least conflicting methods for striving towards international goals to reduce wasteful fishing practices.

Future studies on selectivity of the Nha Trang trawl fleet should concentrate on the pair bottom trawl fleets and the large vessels in the otter trawl fleet. Studies of square mesh panels and grids to improve the selectivity of pair bottom trawl nets could be possible options. For the otter trawlers, only square mesh panel appear to be feasible at present because the fishing equipment used by this fleet is insufficient to operate the net with weighted grid systems. In the longer term, lighter grids made from plastic (i.e., HDPE materials) might be a solution for small trawlers. It is also necessary to assess the effects of the different factors (catch weight, fishing depth, codend circumference and twine diameter of the codend) that normally affect the selectivity performance of the fishery. The decision on a minimum mesh size should be adapted to the status of the fish stocks (i.e., depending on the stock size and the demographic structures of different species). The minimum codend mesh size should be re-assessed and it should probably be larger than the current legal mesh size (28 mm, nominal mesh).

Horizontal separator panel in the trawl is also suggested for future study on the improvement of trawl selectivity of the fishery. The horizontal separator panel devices the trawl into two components and each leads to a separated codend. Ferro at al. (2007) showed that most of haddock, whiting, and saithe moved to the above compartment of a trawl with horizontal separator panel, whereas the lower compartment retained most cod, flatfish, and monkfish. Experiments on the use of horizontal separator panel in Norwegian bottom trawl fisheries in the Barents Sea also showed that most of cod was separated from haddock and saithe (Engas et al., 1998). By using suitable mesh sizes or sorting devices at each codend of a trawl with horizontal separator panel, different sizes and species would be sorted out from the trawl.

Given the views of fishermen, the current prospects for inshore trawl fishery are grim. It is evident that the numbers of fishermen and vessels in the Nha Trang fisheries are not sustainable. All fishermen in the area, including the trawl fleets, struggle to survive and sustain their families but alternative work and income may be scarce. Nevertheless, a reduction of the capacity appears to be the only solution to save the fisheries for future generations.

The introduction of a selective trawl fishery will reduce the instant income for fishermen due to the loss of valuable trash fish. The most likely way of compensating for such losses in the short-term is to improve the efficiency of the gear. The fishermen and boat owners have very limited powers to develop their fisheries into more efficient units. Therefore, it is necessary to look into known methods for reducing operational costs, fuel consumption and for improving the catch-efficiency of legal fish, to develop new fishing grounds and to improve working conditions for fishermen. Research program on the efficient use of fuel which include comparisons on fuel consumption between trawls with and without trash fish reduction devices is suggested.

Simple modifications of the otter boards, bridles and trawl sizes would increase the catch power of the gear and compensate for the lost trash fish in a selective fishery. The rectangular flat otter boards are deploying in the studied fishery. These rectangular flat otter boards are not fuel efficient (Bankston, 1988, SeaFish_Industry_Authority et al., 1993). Changing from flat otter boards to other types of otter boards which are cambered, or fitted with slots or of multifoil design would save the fuel consumption of trawlers since the latter designs of the otter boards stern lower drags and still keep the spreading of the trawls. By re-rigging the otter board in order to reduce the angle attack would also help to reduce the fuel up to 8% (SeaFish_Industry_Authority et al., 1993). According to Eayrs (2012), reduction of the twine diameter from 3 mm to 2.1 mm (wingtips to extension pieces) and enlargement of the diamond mesh of the trawl from 152 mm to 178 mm at the same time would help to reduce the fuel consumption of a trawler by 22.6 %. Using the new twine materials (i.e., Dyneema, Aramid) which are stronger and with less drag than the current materials has been attempted in order to reduce the fuel consumption in trawl fisheries. High initial investment cost would restrict the application of advanced material nets. The Government should propose policy (i.e., loans with suitable interests) to promote the use of the new materials and techniques in fishing.

More mechanization of laborious operations, especially during the hauling process, could reduce the number of crew onboard, or at least make the working day more comfortable. Installing the rope and net-drums at the stern of the vessel would be an option to reduce the labours needed on the trawlers. Health and safety issues are not well developed in the Vietnamese fisheries and this improvement in this area are needed to ensure future recruitment to the fisheries.

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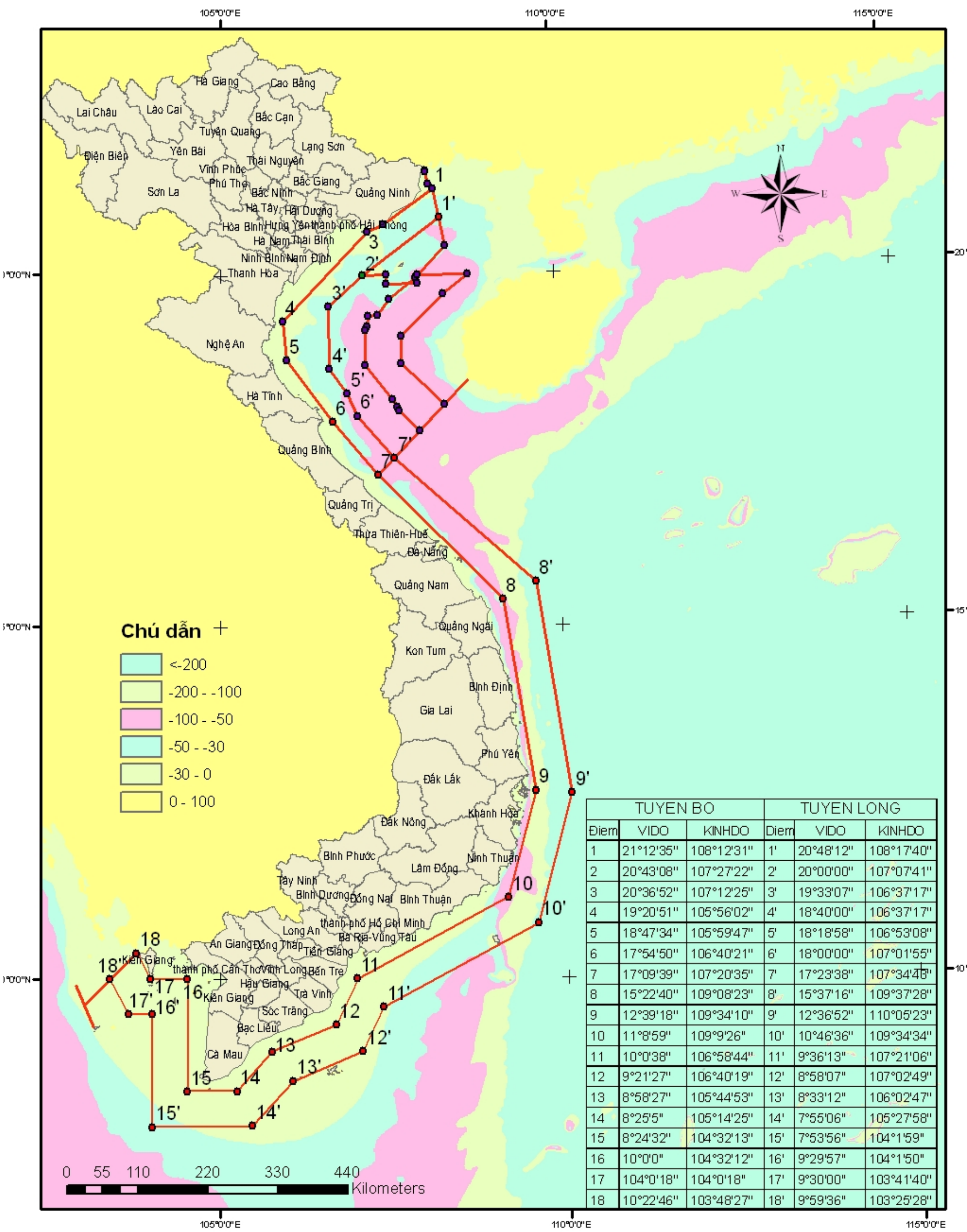
Appendix I. Fishing zones regulated by Vietnamese Government



TUYEN BO			TUYEN LONG		
Điem	VIDO	KINHDO	Diem	VIDO	KINHDO
1	21°12'35"	108°12'31"	1'	20°48'12"	108°17'40"
2	20°43'08"	107°27'22"	2'	20°00'00"	107°07'41"
3	20°36'52"	107°12'25"	3'	19°33'07"	106°37'17"
4	19°20'51"	105°56'02"	4'	18°40'00"	106°37'17"
5	18°47'34"	105°59'47"	5'	18°18'58"	106°53'08"
6	17°54'50"	106°40'21"	6'	18°00'00"	107°01'55"
7	17°09'39"	107°20'35"	7'	17°23'38"	107°34'48"
8	15°22'40"	109°08'23"	8'	15°37'16"	109°37'28"
9	12°39'18"	109°34'10"	9'	12°36'52"	110°05'23"
10	11°8'59"	109°9'26"	10'	10°46'36"	109°34'34"
11	10°0'38"	106°58'44"	11'	9°36'13"	107°21'06"
12	9°21'27"	106°40'19"	12'	8°58'07"	107°02'49"
13	8°58'27"	105°44'53"	13'	8°33'12"	106°02'47"
14	8°25'5"	105°14'25"	14'	7°55'06"	105°27'58"
15	8°24'32"	104°32'13"	15'	7°53'56"	104°1'59"
16	10°0'0"	104°32'12"	16'	9°29'57"	104°1'50"
17	104°0'18"	104°0'18"	17'	9°30'00"	103°41'40"
18	10°22'46"	103°48'27"	18'	9°59'36"	103°25'28"

Zone 1: Water bodies from coast line to the lines: (1-2-3-4-...-18)

Zone 2: Water bodies from the lines: (1-2-3-4-..-18) to lines: (1'-2'-3'-4'-...-18')

Zone 3: Water bodies beyond the lines: (1'-2'-3'-4'-...-18').

Trawling is prohibited in Zone 1.

Appendix II. Shooting and hauling the trawl net

Codend being hauled by hand at the side of a trawler.

Trawl net being hauled by hand on board at the stern of a trawler.

Sorting the catch on the front deck.

Deploying the net.

Appendix III. Explanation of how to construct the equations for L25, L50, L75 and SR from r(L).

$$r(L) = \frac{1}{\frac{1}{\exp\,(\alpha + \beta * L)} + 1} \rightarrow \frac{1}{\exp\,(\alpha + \beta * L)} + 1 = \frac{1}{r\,(L)}$$

$$\rightarrow \frac{\mathbf{1}}{\mathbf{exp(\,\alpha + \beta * L)}} = \frac{\mathbf{1 - r(L)}}{\mathbf{r\,(L)}}$$

$$\rightarrow \mathbf{exp}(\boldsymbol{\alpha} + \boldsymbol{\beta} * \boldsymbol{L}) = \frac{\boldsymbol{r\,(L)}}{\mathbf{1} - \boldsymbol{r\,(L)}} \rightarrow \boldsymbol{\alpha} + \boldsymbol{\beta} * \boldsymbol{L} = \mathbf{ln}\frac{\boldsymbol{r(L)}}{\mathbf{1} - \boldsymbol{r\,(L)}} \quad (*)$$

The equation above (equation *) generate a straight line model or a generalised linear model where α is the "slope" and β is the "intercept". The retention of fish should increase with an increase in the fish length so β should be larger than 0. In addition, the retained proportion of fish with a length of "zero" should also be "zero". Thus, the value of α has a large negative value to satisfy equation (*).

The length with a 50% probability (L50) of retention can be calculated as follows.

$$\alpha + \beta * L50 = \ln(\frac{0.5}{1 - 0.5}) = \ln 1 = 0 \rightarrow L50 = -\frac{\alpha}{\beta}$$

The selection range (SR) (i.e. the difference between L25 and L75) is calculated as follows.

$$\alpha + \beta * L75 = \ln(\frac{0.75}{1 - 0.75}) = \ln 3 \rightarrow L75 = \frac{\ln(3) - \alpha}{\beta}$$

$$\rightarrow \boldsymbol{\alpha} + \boldsymbol{\beta} * \mathbf{L25} = \mathbf{ln}(\frac{\mathbf{0.25}}{\mathbf{1 - 0.25}}) = \mathbf{ln}\frac{\mathbf{1}}{\mathbf{3}} \rightarrow \mathbf{L25} = \frac{\mathbf{ln}\left(\frac{\mathbf{1}}{\mathbf{3}}\right) - \boldsymbol{\alpha}}{\boldsymbol{\beta}}$$

$$\rightarrow SR = L75 - L25 = \frac{\ln(3) - \alpha}{\beta} - \frac{\ln(\frac{1}{3}) - \alpha}{\beta} = \frac{2 * \ln\,(3)}{\beta}$$

Appendix IV. Methods used in selectivity experiments in trawl fisheries

(The covered codend method is described in section 1.5)

- **Twin trawl method**

In some trawl fisheries, double or triple trawl rigs methods are deployed. The selectivity of a test codend can be directly estimated with this method with no covers are applied. The test codend is attached to one net while another codend with a small mesh size (control codend) is attached to the other net. During triple rigs trawling, the middle net can be equipped with a second test codend. This method is based on the assumptions that there are similar quantities of fish entering each net. The experimental costs are reduced because each haul will produce one selectivity curve. The problem of altering fish behaviour does not affect this type of study method. However, there are concerns that bias may occur because the number of fish entering the two nets are not similar. This method may be too complex for the captain and crew members during fishing operations if they are not familiar with this type of trawl rig.

- **Parallel haul method**

Two trawlers are used in this experiment and no covers are applied. One trawler tows the test net while the other tows a net with small meshes in the codend ("control" net). The two trawls are towed side-by-side in the same direction at the same towing speed. It is assumed that similar quantities (numbers) of fish enter both nets. The cost of the experiment is a problem for this type of study because it needs two vessels. In addition, the problem of similar numbers of fish entering the two nets needs to be considered because the two nets may be towed in slightly different positions by the two vessels.

- **Alternate haul method**

In this type of experiment, the trawler first makes a tow with the test codend and the next tow with a small mesh codend. During each haul, the trawler is manoeuvred in the same direction at the same speed and with the same trawling time as the other hauls. No cover is used in this method so there are no concerns on altering fish behaviour. However, at least two hauls are needed to construct one selectivity curve, which increases the experimental costs. In addition, since each haul is towed at different hours of the day and in different positions, the population that enter the test and control codend may differ in size, number and species, hence leading to bias.

- **Trouser trawl method**

A vertical net panel is attached inside the trawl net (from the middle of the ground-rope and floatline to the end of the net body) to split device the trawl net into two equal components. Each component ends with a codend, whereof one is constructed from a small mesh and one has the test mesh size (or selective system). Fish are assumed to enter each codend in similar numbers, sizes and species composition. The advantage of this method is a simple design for a two-compartment trawl.

- **Cover bag to cover the selectivity device**

This method is a special version of the covered codend method. If scientists want to assess the selectivity of a sorting device in a normal codend, a special cover is placed over the device. The construction and rigging of the cover could affect the fish behaviour in the vicinity of the device. In addition, the cover may lie close to the codend when the number of escaped fish in the cover is high. If so, the cover may restrict free escape of the fish through the test device.

Appendix V. Alternative methods for reducing the catch of juveniles in trawl fisheries

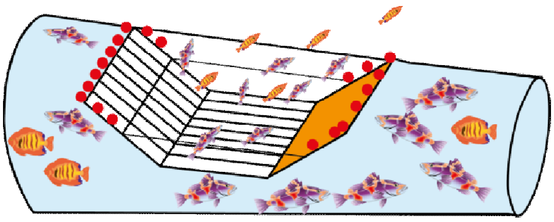
- **Grid systems**

In the 1990s, the Sort-X grid (Fig. 12a) was developed and tested by Norwegian researchers (Grimaldo, 2008, Sistiaga, 2011) in order to reduce the catches of juvenile cod and haddock in the cod trawl fisheries in the area. The Sort-X grid has three panels (two panels with stainless steel grids and one panel covered by canvas), which are installed in the aft part of the trawl net (Larsen and Isaksen, 1993). The working principle of the Sort-X grid aims to help juvenile fish to escape through the spaces between the bars of the grids whereas the adult fish (with larger sizes) do not manage to escape between the bars and are retained in the end of the trawl codend. The Sort-X grid with a 55-mm bar spacing became mandatory for trawlers in the North East Atlantic waters in 1997 (Sistiaga, 2011).

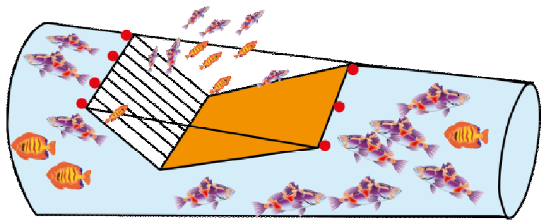
While looking for grid that was lighter and easier to handle than the Sort-X grid, Russian researchers developed the Sort-V (Sistiaga, 2011). The working principles of the two grids are the same, but the Sort-V has two panels (i.e., one panel with grids and another covered by fine mesh) (Fig. 11b). The selectivity performance of Sort-V is similar to Sort-X with the same bar spaces. Thus, in 2000, Sort-V was also accepted for use in Norwegian waters by the fisheries management authorities (Sistiaga, 2011).

Another grid is used to separate juvenile and adults fish, i.e., the “flexi-grid” (Fig. 11c) was developed and tested by the University of Tromsø in Norway and The Foundation for Scientific and Industrial Research in Norway (SINTEF) (Sistiaga, 2011). This grid is made of a soft/flexible rubber frame and fibreglass bars, which makes it lighter and more flexible than any steel grid. This grid is a two-grid system that is similar to two Sort-V grids, although they are rigged in a different way (Fig. 11c). In addition to the application of new materials, the idea of a flexi-grid also provides more opportunities for juvenile fish to escape (O’Neill et al., 2008). The Sort-V and Flexi-grid are popular in Norwegian and Russian trawlers.

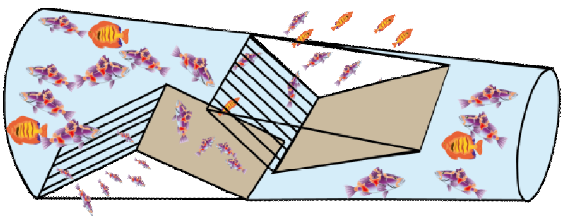
In the 2000s, the Southeast Asian Fisheries Development Centre (Seafdec) developed and tested a Juvenile and Trash Fish Excluder Device (JTED) in several countries in the Southeast Asian region (Chokesanguan, 2005, Chokesanguan, 2000, Chokesanguan, 2002, Eayrs, 2007). The working principle of JTED is similar to that of Sort-X. The differences are the sizes and the bar spacing of the two grid designs. JTED with a bar spacing of 20 and 30 mm releases 12–28% by weight of the total trash fish (Chokesanguan, 2002). Another experiment in Thailand showed that 5–20% (by weight) of the trash fish were released through the JTEDs (Chokesanguan, 2002). JTED has some benefits for excluding trash fish but it remains at the experimental stage. In addition, there were comments from fishermen who participated in the experiments of JTED about handling issues, the weight of the grids and the loss of catch (Eayrs, 2007).



(a)



(b)



(c)

Figure 11. Sorting grids used to exclude juvenile fish. (a) Sort-X grid; (b) Sort- V grid; (c) Flexi-grid.

- **The T90 codend**

The T90 codend is constructed from diamond mesh panels that are turned 90 degrees (T90). The T90 codend helps to increase the L50 for cod in Baltic trawl cod fisheries (Wienbeck et al., 2011). The T90 codend reduces the catch of under-sized and legal-sized Norway lobster in combined fish and Norway lobster trawl fisheries (Madsen et al., 2012). The T90 codend also retains more under-sized plaice than the conventional diamond mesh codend (Madsen et al., 2012). Using the same mesh size and codend circumference, T90 codend retained less small cod and haddock than the conventional diamond mesh (Digre et al., 2010).

The T90 codend with a minimum mesh size of 110 mm was added to the legislation for the Baltic Sea cod fishery (Madsen, 2007).

- **Codend design**

A simple modification of a codend can help to improve the size selectivity of a trawl. A reduction in codend circumference can increase the L50 for several fish species. After increasing (do you mean reducing?) the codend circumference by 13–17% of the original size, the L50s for red mullet (*Mullus barbatus*), little squid (*Alloteuthis media*) and European hake (*Merluccius merluccius*) were reduced by 9–41% (Sala et al., 2007). Thus, the codend circumference was added to legislation to control the selectivity of North sea fisheries (Graham et al., 2007). In addition to the circumference, the codend length can affect the selectivity of diamond mesh codends. Adding lastridge ropes along the codend seams (i.e., about 5% shorter than the codend length) to the codend helps the diamond mesh remain more and longer open during operation, which increases the possible escape of small fish (Eayrs, 2007). Furthermore, and as mentioned in section 1.4, a reduction in the twine diameter of diamond mesh codends can help to increase the L50.

Papers

Paper 1

Paper 2

Paper 3

Paper 4

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